A Comparative Case Study of Code Reuse With Language Oriented Programming*

David H. Lorenz[1] and Boaz Rosenan[2]

Open University of Israel,
1 University Rd., P.O.Box 808, Raanana 43107 Israel,

[1] lorenz@openu.ac.il,
[2] brosenan@cslab.openu.ac.il

Abstract. There is a gap between our ability to reuse high-level concepts in software design and our ability to reuse the code implementing them. Language Oriented Programming (LOP) is a software development paradigm that aims to close this gap, through extensive use of Domain Specific Languages (DSLs). With LOP, the high-level reusable concepts become reusable DSL constructs, and their translation into code level concepts is done in the DSL implementation. Particular products are implemented using DSL code, thus reusing only high-level concepts. In this paper we provide a comparison between two implementation approaches for LOP: (a) using external DSLs with a projectional language workbench (MPS); and (b) using internal DSLs with an LOP language (Cedalion). To demonstrate how reuse is achieved in each approach, we present a small case study, where LOP is used to build a Software Product Line (SPL) of calculator software.

1 Introduction

A key issue with software reuse is the gap between concept reuse and code reuse. Many abstract concepts, such as a state machine, are often reused across substantially different software products. However, on the code level, their implementations are tangled with details of particular products and often cannot be reused.

This loss of reuse can be attributed to the abstraction gap between the high-level (concept level) and the low-level (code level) representations of the solution. When programmers implement a high-level concept, such as a state machine, they “compile” the high-level concept into code in a manual process. The product of this process is code that integrates, often in an inseparable manner, the reusable knowledge of how to code such a concept in the programming language in use (e.g., a state machine design patterns), with the specifics of the particular instance of the concept (e.g., a particular instance of a state machine).

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One solution to this problem is the use of *Domain-Specific Languages (DSLs)*. Programmers use DSLs to code high-level concepts directly. The DSL implementation is responsible for specifying the meaning of these concepts in terms of lower-level concepts. This can be done either by compiling the DSL code into code in some pre-existing language, or by interpreting it. Either way, the application code now consists of two parts: the DSL code and the DSL implementation. The DSL code conveys the specifics of the application, which is generally not reusable but very concise. The DSL implementation conveys the knowledge of expressing high-level concepts in terms of low-level ones, which is often complicated, but highly reusable. This method thus allows us to take reusable concepts and turn them into reusable code, expressed as the DSL implementation.

Indeed, DSLs can be used to solve this abstraction gap and achieve higher code reusability. However, for this method to take effect in real-life software development, it has to be applied systematically throughout the code. Real-life software is complex and diverse. It usually uses many kinds of high-level concepts. Some are globally relevant (e.g., a state machine), but some are only relevant to an industry or a particular software product-line (SPL).

Using DSLs for these concepts can allow reusing the logic behind them. This means that DSLs must be developed for various aspects of the software, and that these DSLs need to be able to interact, in the places where one high-level concept touches another, e.g., when a network event (one high-level concept) triggers a state transition in a state machine (another high-level concept). Having such interactions requires that the DSLs be implemented over some common platform that allows DSLs to interact, both syntactically and semantically. This approach to software development, which advocates the use of interoperable DSLs to write software, is called *Language Oriented Programming* (*LOP*) [11,1,2].

The main challenge for realizing LOP in real-life software lies in the need to develop and use DSLs. Here, the choice of techniques and tools used for DSL implementation bears a great significance on the practicality of LOP. For example, the traditional approach of using standard compiler-generator tools such as Lex and Yacc or ANTLR to implement DSLs can work properly for a pre-determined, limited set of concepts, but will not allow DSLs to be defined as separate, reusable but interoperable components.

One important decision one needs to make is the choice between internal and external DSLs [2]. *External DSLs* are DSLs implemented in form of a compiler, translator or interpreter for the DSLs, while *internal DSLs* (or *embedded DSLs* [3]) DSLs are "sub-languages" defined from within a host language. Internal and external DSLs have inherent trade-offs. On the one hand, external DSLs provide more freedom in defining syntax and semantics, but place the burden of implementing the language on the DSL developer. On the other hand, internal DSLs are much easier to implement, as they reuse most of the facilities provided by the host language, but are constrained by its syntax and semantics. In addition, DSL interoperability is supported naturally by internal DSLs (where all the DSLs are actually code in the same host language), while interoperability is much harder to achieve using external DSLs.

To date, two approaches have been presented to overcome these trade-offs, namely *language workbenches* and *LOP languages*. Both of these approaches allow to develop one kind of DSLs, while mitigating its limitations relative to the other kind:

Language Workbenches Language workbenches are integrated development environments (IDEs) for developing external DSLs. They ease the task of defining and implementing DSLs by providing (meta) DSLs dedicated for that task. They provide some tooling (auto-completion, definition search, etc.) for the DSLs for free, or at very little cost, by leveraging the DSL definition. Language workbenches, in contrast to other compiler-generation tools, are made to support DSL interoperability. The most notable language workbenches are MPS [1] and the Intentional Domain Workbench [8]. They both use *projectional editing*, an approach were the program is a model edited through a view, as a replacement for using text editing and parsing. This allows syntactic integration of DSLs without causing ambiguity. With projectional editing, disambiguation is done when entering the code, e.g., by selecting the intended construct from a list or a menu.

LOP Languages This is a new concept presented by our group [7]. These are programming languages oriented towards LOP, similarly to how object-oriented programming languages are oriented towards OOP. By our definition, LOP languages are made to host internal DSLs, while providing two important features previously associated with language workbenches and external DSLs. These are: projectional editing, and the ability to define and enforce DSL schemata. The Cedalion language [5] is an example of such an LOP language, based on logic programming for hosting internal DSLs, with a static type system to provide a basic notion of DSL schema.

The main difference between these two approaches is in the relationships between languages in each framework. In language workbench we can identify three: the DSL code, the DSL implementation (the meta level), and the workbench provided DSLs for implementing DSLs (the meta-meta level). LOP languages, on the other hand, provide all these function from within a single programming language. In a way, this is their advantage, allowing reuse across these levels.

In this work we implemented twice, as a case study, a simple SPL of *calculator software*, using two LOP techniques. One of the implementations is based on external DSLs and the other on internal DSLs. The differences between the two implementations provides a comparison in terms of the cost of reuse between external and internal DSL. It also provides a deeper understanding of LOP and how LOP can generally address the issue of code reuse in SPLs.

Specifically, we implemented the complete SPL in MPS and another complete implementation in Cedalion. We present the two implementations and discuss the pros and cons of each method. The choice of MPS and Cedalion as the implementation tools for this paper was made due the fact that their main difference is in the choice of external (MPS) versus internal (Cedalion) DSLs, thus providing a comparison between these two approaches. In other LOP respects they are similar (projectional editing, DSL schema).We concentrate on the cost

of achieving code reuse in these two approaches. We conclude that both approaches indeed support reusability by providing easy-to-use DSLs that hide the complexity of translating high-level concepts into low-level, executable ones. However, the difference between these LOP approaches lies in the DSL implementation. Implementing internal DSLs over a declarative language is easier and more straightforward than implementing external DSLs over an imperative language.

2 Case Study: Calculator Product Line

To get the feel of how practical and useful LOP can be, and to study the implications of using internal versus external DSLs, we present here a small comparative case study, where we use LOP to create a tiny SPL for calculator software. Our measurements will be both qualitative (how well did we manage to reuse code) and quantitative (the cost, in terms of implementation time). We conduct this study using two tools: the MPS language workbench, and the Cedalion LOP language.

Meta-Programming System (MPS) This is a projectional language workbench (i.e., a language workbench using projectional editing) developed by Dmitriev and his team at Jetbrain's [1]. It is mostly open source, and can be freely downloaded. This made it a good candidate for this case study. Its website contains examples and tutorials to help new users get up-to-speed. It features relatively mature and very powerful projectional editing capabilities, overcoming some of the usability problems traditionally associated with projectional editing. DSL implementation is typically done by generating code in a language called the "base language," which is, for all practical purposes, Java. Implementing a DSL in MPS requires creating templates and conversions for all DSL constructs into lower-level languages, and eventually, into the base language.

Cedalion Cedalion is an LOP programming language, based on logic programming. Logic programming provides a declarative way to define DSL semantics, while its static type system provides a structural definition (a schema) for the DSL. Like MPS, it features projectional editing, which allows syntactic freedom for DSL developers, without the danger of creating ambiguities, since disambiguation is done when entering the code. Cedalion is open source (`http://cedalion.sourceforge.net`). Its projectional editor is implemented as an Eclipse plug-in, using a Prolog back-end. Cedalion, however, is a research tool developed as a proof-of-concept and as such lacks the maturity that MPS provides. Nevertheless, Cedalion is more than capable to implement the case study at hand.

2.1 The Problem Statement

To examine the value of LOP for code reuse, and to compare between internal and external DSLs for this purpose, we define a problem, which we shall solve using the above tools. The problem statement is as follows:

> Develop an SPL of calculator software. All calculators have a key-pad and a line-display. On the key-pad there are numerous keys for digits, operators and functions. Pressing these keys simply append characters to the line-display. There is also an "execute" or "=" button, which, when pressed, replaces the expression in the display with either the number to which the expression evaluates to, or the string "Syntax Error", if the expression is invalid.

Since we are interested in a SPL, we refer to a whole product-line of such calculators. These calculators differ in their choice of operators, functions, and even digits (e.g., a hexadecimal calculator), and how they evaluate to numbers. Our goal in this case study would be to try and reuse as much code as possible between different calculators in this SPL.

2.2 General Guidelines

In this case study we focus on the part of the software that parses and evaluates the string into a value, assuming the rest of the software (e.g., the line editing) are inherently reusable between different calculators.

We will implement these calculators using LOP. This means that we will first identify the high-level concepts we need to describe *a calculator*, regardless of the specific instance (scientific, financial, etc.). We then define a DSL to express these concepts formally, and implement it. In this case study we ignore any pre-existing DSLs that may address these concepts, since we would like to aim for the real-life scenario where such DSLs are often unavailable or inapplicable for various reasons. We then implement each calculator using the DSL we developed. These implementations are expected to be concise and very high-level, expressing the syntax of each particular calculator. All the logic common across calculators is expressed in the DSL implementation. Reuse of calculator features expected to be common to different calculators (such as the parsing of numbers and basic arithmetic operations) is beyond the scope of the case study, and will be addressed briefly in Sections 3.3 and 4.2.

3 SPL Implementation in MPS

We now describe the calculator SPL implementation in MPS. Due to space limitation we keep the MPS-related implementation details as brief as possible.

3.1 Defining the DSL

We begin by analyzing our calculator SPL, in order to figure out what kind of DSL(s) we need to define for it. Our software needs to do two things: (1) parse a string, according to some grammar; and (2) calculate a numeric value based on that parsing. We therefore wish to implement our calculator using a DSL that combines a grammar (context-free) and the evaluation of expressions. This

is somewhat similar to an attribute grammar, where each production rule is associated with a single value. Existing DSLs, such as Yacc [4] can be considered here. However, as stated in Section 2.2, for the purpose of the case study we ignore pre-existing DSLs and implement the ones we need. For the purpose of this discussion we consider the '+' operator. Its syntax can be defined as:

$$expr ::= expr,\ '+',\ multExpr \tag{1}$$

We would evaluate *expr* for Eq. 1 by summing the values of the derived *expr* and *multExpr* non-terminals. This could be formulated as:

$$expr ::= a = expr,\ '+',\ b = multExpr\ \{a + b\} \tag{2}$$

by binding the result of evaluating both arguments with variables a and b (using the = operator), and then specifying that the entire phrase evaluates to $a + b$, inside the curly braces.

This notation is clear and concise, however, making it executable is far from trivial. The grammar in Eq. 1 has a head recursion, making it non-LL (this is actually an LR grammar). Parsing LR grammars is significantly harder than parsing LL grammars. LL grammars can be parsed using recursive descent, with reasonable effort. Generating a parser for even a subclass of LR (such as LALR(1)) is a much harder task [4]. We therefore would like to restrict ourselves to LL grammars, and for that we need to avoid head recursion. To make Eq. 1 an LL grammar, we need to replace the head recursion with a tail recursion:

$$\begin{aligned} expr &::= multExpr,\ exprSuffix \\ exprSuffix &::= '+',\ expr \end{aligned} \tag{3}$$

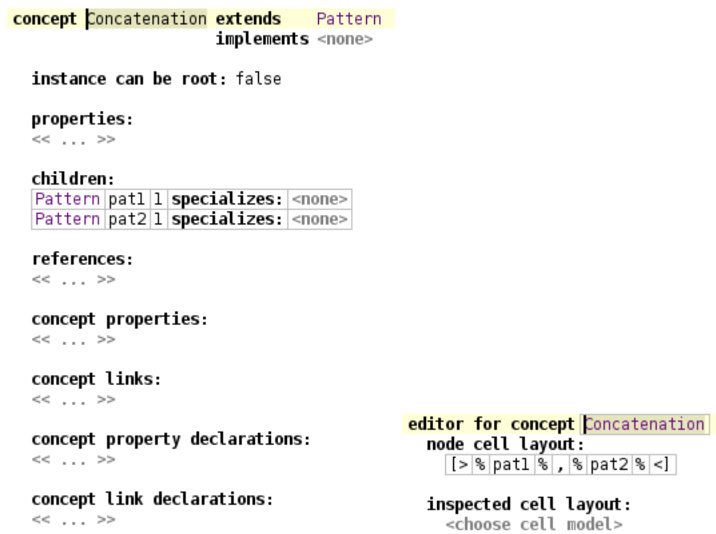
This changes the way we calculate the value. We need to adopt a top-down approach for the evaluation. Such calculation can be formalized as follows:

$$\begin{aligned} expr &::= a = multExpr,\ s = exprSuffix(a)\ \ \{s\} \\ exprSuffix(a) &::= '+',\ b = expr\ \ \{a + b\} \end{aligned} \tag{4}$$

An *expr* consists of a prefix (*multExpr*) and a suffix (*exprSuffix*). We first parse the prefix and bind its value to variable a. Then we parse the suffix, providing it the value of a as argument. The suffix modifies the value by adding the right-hand value (variable b) to the parameter a. Finally, *expr* returns the value returned from the suffix.

The notation used in the example in Eq. 4 is sufficient for expressing the logic of an entire calculator in our case study.

DSL Schema Now that we understand what our DSL looks like, we need to break it down and understanding which constructs our DSL has, and more importantly, how they are classified. The notation in Eq. 4 holds four "families" of constructs: Rules, Patterns, Reducibles and Expressions. Most important is the distinction between patterns and reducibles. Both patterns and reducibles define languages of strings, however, a reducible reduces a string to a single



(a) Concept definition (b) Editor definition

Fig. 1: Definition of the Concatenation concept in MPS

value, whereas a pattern reduces a string into a set of variable bindings. For example, $'+', e = expr$ is a pattern, as it produces the bindings for e, while the more complete term $'+', e = expr\,\{p + e\}$ is reducible, since it defines a single value $(p + e)$ for the string being parsed.

DSLs in MPS can rely on other languages. In this case, we use the *Expression* concept defined in the MPS *base-language* [1] as our expression type, so our language will inherit the wealth of expressions supported by the base language with no effort on our part. We do, however, need to define two expression concepts of our own: a reference to an argument (such as p in the term $\{p + e\}$ in Eq. 4), and to a bound variable (such as e in the term $\{p + e\}$ in Eq. 4). These new expression concepts will integrate seamlessly into base-language expression concepts such as the '+' expression.

In MPS, a DSL schema is defined by defining the language's *structure model*. This model consists of *concepts*, which are each defined using its own form. The concept definition resembles a class definition. It contains the concept's name, base-concept, implemented interfaces, child concepts, referenced concepts, properties, etc. For child and referenced concepts, cardinality should be provided. Table 1 lists the concept in our DSL. Figure 1a shows the definition of *Concatenation*, as an example for a concept definition. Note that this is a screenshot and not code listing, due to MPS's projectional nature.

Concept	Base Concept	Projection	Description
Alternative	Reducible	$a \mid b$	Choice between two reducibles
Concatenation	Pattern	a, b	Concatenation of two patterns
Empty	Pattern	$<$ empty $>$	A pattern matching an empty string
Grammar	-	grammar *name* *rules...*	A full grammar
NamedPattern	Pattern	$v = r$	Assigning a name to the value produced by reducible r
NamedPattern Reference	Expression	*name*	An expression evaluating to the value returned from parsing the reducible associated with name
NonTerminal	Reducible	$name(args...)$	References the rule named *name*, providing it arguments *args*
PatternValue	Reducible	$p\{e\}$	Evaluates to the value of e, with the variable bindings received from p
Rule	-	$name(args...)::=r$	A production rule in the grammar
RuleArgReference	Expression	*name*	An expression evaluating to the value of an argument given to the rule
RuleArgument	-	*name*	A formal argument for a rule
Terminal	Pattern	$'string'$	A pattern matching a constant string

Table 1: List of concepts in the Grammar DSL

Defining the Editors To allow projectional editing, we need to define how each concept is visualized and edited. In MPS we do this by defining an *editor model*. Figure 1b shows the editor definition for the *Concatenation* concept.

Language Refinements Now the language is defined, although we have not yet implemented it. However, two refinements are in order:

1. Limiting the scope of rule arguments to the rule they are defined in, and limiting the scope of variables to the pattern they are defined in. These are done by defining a *constraints model* for these concepts.
2. Making the type of both variables and arguments "double," when used in expressions. In addition, expressions associated with patterns must also evaluate to "double." These rules are specified in a *type system model*.

We omit screenshot of these definitions due to space limitations.

3.2 Implementing the DSL

A generator translates the DSL code into a lower-level, executable language, making the DSL executable. This translation defines the semantics of our DSL.

Before implementing a generator we need to decide on a target language. In MPS, if Java is an acceptable output language, the MPS *base-language* [1] will be a natural choice. This is an adaptation of Java to MPS including most of its features (MPS1.1 does not yet support generics), but like all other MPS-based languages, it is edited using a projectional editor.

The more interesting question we need to ask is how do we wish to see our DSL program translated to that target language (i.e., Java). In our case, this means how do we wish to implement a parser or evaluator in Java (or a Java-like language). We already mentioned that we prefer top-down parsing (LL) over bottom-up (LR), since the latter requires some heavy algorithms which we wish to avoid in this case. Therefore, we need to understand how to implement a recursive descent parser in Java. There are several ways to do that with performance–simplicity trade-offs. Here we prefer simplicity over performance, and specifically we prefer the simplicity of the *generator*, and not necessarily that of the *generated code*.

The biggest challenge in this translation is the need for backtracking. In this case, backtracking is used to support look-ahead. With backtracking, the parser can go forward several characters following a certain alternative, not find what it is looking for, and then backtrack to the point when it made the choice and re-parse the text using a new alternative. This technique is expected to be simpler (in terms of generator code) then a possible alternative of turning the non-deterministic state machine into a deterministic one, with no backtracking. One of the main challenges of introducing backtracking is with regard to variable bindings. In our DSL we bind values to variables. These values may change due to backtracking. We need a way to save not only the state of parsing, but also the value of variables, and restore them when backtracking. Some declarative languages, such as Prolog, provide natural support for backtracking. Variable bindings in these languages obey backtracking. In fact, variables in these languages do not change their value with time *except* with backtracking.

The semantics of Java (and hence the MPS base-language) does not have natural support for backtracking. Therefore, one of our challenges would be to build backtracking "from scratch."

Implementing a Generator Here we define the semantics of our DSL. This is done using *mapping rules* and *reduction rules*. Mapping rules define how concepts in the model map into top-level concepts in the generated code. A class in the base-language is a top-level concept, so we map each grammar to a class, using a mapping rule. The mapping rule specifies a template of the class, which lays out the general structure of a class generated to implement a grammar. This template uses macros to customize the output class based on the properties and children of the grammar. One kind of macro, *COPY_SRC*, is used to copy child nodes into place in the template. This "copying" includes reduction where needed, following the reduction rules specified for the generator. *Reduction rules* define how a DSL concept is translated to lower-level concepts, usually concepts of the base language. In our DSL, reducibles and patterns have reduction rules, transforming them into expressions in the base-language, resulting in an object

```
[concept     Concatenation] --> <T  new IPattern() {                                                    T>
[inheritors false        ]         private Parser.IPattern pat1 = $COPY_SRC$[null];
[condition   <always>     ]         private Parser.IPattern pat2 = $COPY_SRC$[null];

                                   public void parse(String string, Map bindings, final Parser.IBindingTarget
                                       target) {
                                     final Parser.IPattern pat2_ = this.pat2;
                                     this.pat1.parse(string, bindings, new IBindingTarget() {
                                       public void handleBinding(String residue, Map bindings) {
                                         pat2_.parse(residue, bindings, target);
                                       }
                                       <add members (ctrl+space)>
                                     });
                                   }
                                   <add members (ctrl+space)>
                                 }
```

Fig. 2: Reduction rule for *Concatenation*

implementing *IReducible* and *IPattern* respectively. Figure 2 shows the reduction rule associated with the *Concatenation* concept. It produces an instance that when getting a string it will first pass it through the *IPattern* associated with its left-hand argument, passing each result (received using a callback) to the *IPattern* associated with its right-hand argument. The *COPY_SRC* macros replace the *null* values with the reduction of the left and right-hand arguments of the concatenation.

3.3 Implementing the Calculator

Now that our DSL is defined and implemented we can move forward to using it to implement a concrete calculator. Figure 3 shows an implementation of a simple calculator, accepting numbers, the four basic arithmetic operations and parentheses. This definition is indeed short, concise, and contains nothing of the *algorithm* required to actually parse the string and to evaluate it. It only contains the *rules* by which this will be done.

Each member of our product line should have such a definition, defining its precise syntax and semantics. Since all implementation details are encapsulated in the DSL definition (the generator model), they are fully reused between these SPL instances.

DSL Code Reuse As concise as it may be, with complex enough calculators it may not be enough to reuse the logic hidden in the DSL implementation. DSL code duplication may become a problem as well. For example, the features defined in Figure 3 may be desired in all calculators. Scientific calculators may add, e.g., trigonometric functions, and financial calculators may add percentage calculations; but both will keep this core behavior. One simple solution for that would be to use inheritance, thus the scientific and financial calculator grammars will inherit from the basic calculator grammar, adding their own specific functionality. However, inheritance can go only a certain way. Supporting an assortment of calculator, each with an arbitrary selection of features will not work well with inheritance. Völter [9] presents an approach to SPL engineering of DSL code in projectional language workbenches, and has implemented it in MPS. With his

```
grammar CalculatorGrammar
digit (  ) ::= ' 0 ' { 0 } |
               ' 1 ' { 1 } |
               ' 2 ' { 2 } |
               ' 3 ' { 3 } |
               ' 4 ' { 4 } |
               ' 5 ' { 5 } |
               ' 6 ' { 6 } |
               ' 7 ' { 7 } |
               ' 8 ' { 8 } |
               ' 9 ' { 9 }
integer ( numToTheLeft ) ::= firstDigit = digit (  ) , restOfNumber = integer ( numToTheLeft * 10 + firstDigit ) {
                                  0 + restOfNumber } |
                             <empty> { numToTheLeft }
number (  ) ::= wholePart = integer ( 0 ) , fractionPart = fractionOpt ( 0.1 ) { wholePart + fractionPart }
fractionOpt ( multiplier ) ::= ' . ' , fraction = fraction ( multiplier ) { 0 + fraction } |
                               <empty> { 0 }
fraction ( multiplier ) ::= firstDigit = digit (  ) , restOfFraction = fraction ( multiplier / 10 ) {
                                 firstDigit * multiplier + restOfFraction } |
                            <empty> { 0 }
expr (  ) ::= primary = multExpr (  ) , suffix = exprSuffix ( primary ) { 0 + suffix }
exprSuffix ( primary ) ::= ' + ' , other = expr (  ) { primary + other } |
                           ' - ' , other = expr (  ) { primary - other } |
                           <empty> { primary }
multExpr (  ) ::= primary = atomicExpr (  ) , suffix = multSuffix ( primary ) { 0 + suffix }
multSuffix ( primary ) ::= ' * ' , other = multExpr (  ) { primary * other } |
                           ' / ' , other = multExpr (  ) { primary / other } |
                           <empty> { primary }
atomicExpr (  ) ::= number (  ) |
                    ' ( ' , value = expr (  ) , ' ) ' { 0 + value }
```

Fig. 3: A calculator implementation

approach, DSL code can be annotated with feature-specific markers. A configuration selecting the desired features controls code generation, so that only the code that contributes to desired features takes effect. This approach can be applied here, associating grammar rules with features. Consequently, by enabling and disabling features we can control the insertion and removal of grammar rules.

4 SPL Implementation in Cedalion

4.1 Defining and Implementing the DSL

We wish to define and implement a DSL similar to the one described in Section 3.1, but this time, we use the internal DSL approach, where we implement each language construct directly, and not by implementing a code generator for the language. This difference allowed us to separate the language definition into two separate DSLs: (1) A "generic" DSL for BNF grammars, and (2) an extension of that DSL to support evaluation ("Functional BNF", or FBNF). The concepts of *Pattern* and *Reducible* exist here too, but the "generic" BNF DSL only supports patterns, while the FBNF DSL introduces reducibles. FBNF uses Cedalion's *Functional* DSL (a functional programming language over Cedalion) for expressions. Table 2 shows all concepts in both DSLs. There are only five of them (four in BNF and one in FBNF). This is due to the fact that some concepts (e.g., variables, alternatives) are inherent in Cedalion, due to its logic programming nature. Other concepts, such as the $name(args...)$ reducible, will be defined concretely for each reducible type, in the calculator definitions.

Figure 4 shows how a concept (in this case, A, B), is defined and implemented in Cedalion. The first line is the type signature (comparable with the *concept*

DSL	Concept	Type	Description
BNF	A, B	pattern	Concatenation of two patterns
BNF	ε	pattern	A pattern matching an empty string
BNF	$head ::= body$	statement	A production rule. Both *head* and *body* are of type *pattern*.
BNF	$'string'$	pattern	A pattern matching a constant string
FBNF	$Reducible \rightarrow^{Type} Expression$	pattern	A pattern that associates a Reducible with an Expression of type Type.

Table 2: List of concepts in the Cedalion BNF DSL

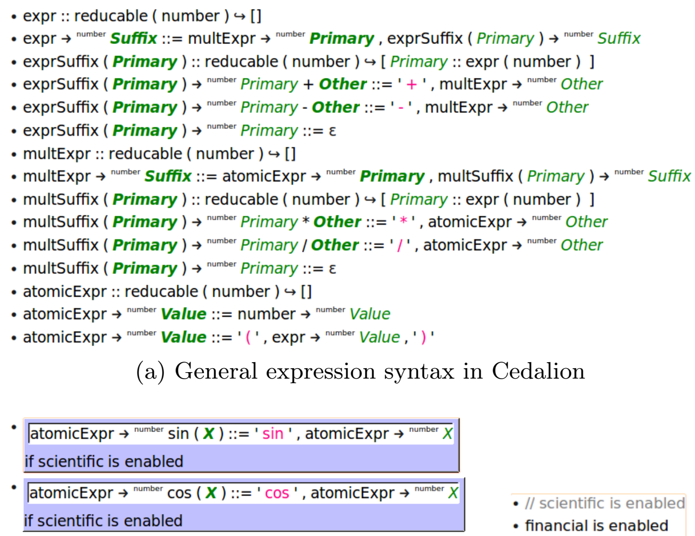
```
• A , B :: pattern ↪ [ A :: pattern , B :: pattern ]
• A , B :: pattern ↠ ʰ [ 《 A :: pattern 》 , " , " , 《 B :: pattern 》 ]
• , is an alias for A , B :: pattern
• A , B ⇒ Text / Residue :-
      A ⇒ Text / Mid ,
      B ⇒ Mid / Residue
```

Fig. 4: Implementation of the *conc* concept in Cedalion

definition in MPS). It defines A, B to be a pattern, given that both A and B are patterns. The second line is the projection definition, comparable with MPS's *editor definition*. It states that this concept shall be displayed as a horizontal list (the tiny "h") of visuals, starting with a placeholder for the projection of A, followed by a comma, followed by a placeholder for the projection of B. The third line defines an alias for this concept, allowing the user to type a comma and get auto-completion suggesting this concept. The last line defines the semantics of A, B. It does so in a Prolog-like manner, by contributing a clause to the $Pattern \Rightarrow Text/Residue$ predicate. This predicate states that $Pattern$ derives a prefix $Pref$ of $Text$, such that $Text = Pref \cdot Residue$. The clause here parses $Text$ as A, B by first parsing $Text$ as A, taking the residue Mid and parsing it as B. The residue now is the overall residue. Similar definitions exist for all the other concepts. Backtracking and variable bindings are handled implicitly, as they are inherent in logic programming, simplifying the implementation significantly.

4.2 Implementing the Calculator

Figure 5a shows part of the implementation of a simple calculator in Cedalion, using the BNF and FBNF DSLs we defined. We omitted the part that defines the syntax of numbers, due to space limitations. This definition is more elaborate then the one in Figure 3 due to the need to specify type signatures for all reducibles. Unlike MPS, where concept definitions exist only in the DSL definition, in Cedalion the DSL code is allowed and encouraged to define new concepts. This allows safe usage of not only DSL constructs, but also of concepts defined by



(a) General expression syntax in Cedalion

(b) Trigonometric functions for scientific calculators

(c) Configuration example

Fig. 5: Calculator implementation in Cedalion

the user, relieving the DSL developer from specifying custom type system rules. While insisting on having type signatures present in the code, Cedalion offers to add them automatically. The syntax here is slightly different then the one we defined with MPS, because while the DSL in MPS was designed as one monolithic DSL, here we see a composition of two DSLs, trying to reuse their language constructs as best we can. This is why we have the $Reducible \rightarrow^{Type} Expression$ concept on both sides of the production rules (on the right, replacing the MPS *NamedPattern* concept, and on the left, replacing the *PatternValue* concept (see Table 1). The *Alternative* in the MPS implementation is not needed here, as different statements (or in this case, production rules), are taken as having an *or* relation, due to the nature of logic programming.

DSL Code Reuse As in Section 3.3, two approaches can be considered here: grammar inheritance or associating rules with features. Since our BNF DSL does not have a concept of a grammar, the first option is inapplicable (recall that this option has significant drawbacks). However, associating rules with features is easy, and can be done from outside the DSL [9]. Even though only full statement can be associated with features, with feature variability [9] this is not a limitation here, because we only intend to do so with full production rules, which are statements. Figure 5b shows how do we support trigonometric functions only if the *scientific* feature is enabled. Figure 5c shows a configuration, where the *financial* feature is enabled, but the *scientific* feature is not.

5 Results, Discussion and Related Work

In previous sections we described a case study, where we used two different tools: MPS and Cedalion, representing two different approaches to DSLs, external using imperative base languages and internal using a declarative host language, to construct a SPL of calculator software, to achieve the goal of maximum code reuse between products. Indeed, the use of DSLs (regardless of their implementation approach) improved reusability by placing the complexity in a shared asset, the DSL implementation. The particular assets in both implementations are stated in a high-level language, capturing the high-level concepts of the problem domain. With methods for associating DSL code with specific features, we can maximize code reuse even at the DSL level, bringing code duplication to zero. We therefore can conclude that we have achieved our goal of code reuse through LOP.

But at what cost? Here the choice of tools takes effect. We measured the time it took to implement and test the first, simplest calculator (four arithmetic operations and parentheses), including the time it took to define and implement the DSL behind it. With MPS it took us about eight hours of work, most of which were dedicated to creating the generator, which was not trivial (implementing backtracking and variable bindings that adhere to backtracking in a Java-like language). In Cedalion it took about two hours. The main challenge there was dealing with the tool's sensitivity to user errors (i.e., its tendency to crash due to them). As evidence for this difference in effort, one can look at the complexity of the DSLs we defined in both tools. It takes significantly less time to implement five constructs than to implement twelve. Moreover, backtracking and variable binding were given for free by the host language. No type system extensions were needed, apart from defining a type signature for each construct. Once the DSLs were defined and implemented, using them was relatively similar in effort. MPS is more mature and therefore is more usable. Cedalion requires type signatures for each new concept (including ones defined in DSL code), which takes a little effort and makes the code a bit more elaborate. However, these differences are minor relative to the difference in effort in implementing DSLs. We therefore conclude that from the view point of this case study, internal DSLs seam to be a more cost effective for achieving code reuse through LOP.

5.1 Threats to Validity

In this work we used implementation time to measure cost efficiency. It may be argued that our familiarity with Cedalion introduced a bias in its favor. However, we took that into account, and familiarized ourselves with MPS well enough before starting this case study, so that the eight hours the implementation took did not include any of the "learning curve."

Another concern that may rise is the fact that we defined the case study ourselves, and it may therefore be biased in favor of internal DSLs, and Cedalion in particular. Specifically, the need for backtracking and variable bindings turns the tables in favor of Cedalion. However, these concepts are needed for many

declarative notations. This is why they are so fundamental in logic programming. We chose this case study because it is relatively small and self contained, and at the same time not trivial.

5.2 Related Work

The first notable work on code reuse through systematic use of DSLs was done by Neighbor [6]. This work introduces Draco, a generative DSL framework. Draco's limitation in comparison with MPS and Cedalion is in its dependence on parsing, which is sensitive to conflicts that can arise when fusing the syntax of several DSLs together.

The term LOP has been coined by Ward [11], who mentioned reuse as one of its primary goals. It was then used by Dmitriev [1] and Fowler [2]. Their notion of LOP is a bit different than Ward's, as they emphasis the need for DSL interoperability. DSL interoperability widens the opportunities for code reuse as the DSLs become small, reusable components. However, Dmitriev [1] and Fowler [2] do not explicitly mention code reuse as a goal for LOP.

At the heart of this paper is a comparison of two approaches to LOP: internal and external DSLs. To our knowledge, not many such comparisons have been proposed. The Language Workbench Competition (LWC) [10] provides a suggestion for comparison between language workbenches. It provides a common task that should be implemented on different workbenches to allow learning about their trade-offs. However, this task does not tell a full story. It specifies a particular DSL, but does not specify the semantics for that DSL. As a result, we found the LWC less helpful for assessing reuse, and therefore turned to define our own.

6 Conclusion

In this paper, we demonstrated how LOP can be used for code reuse, allowing a separation-of-concerns between the generic, reusable high-level concepts used to describe the problem and its solution, and the concrete definition of a particular instance in a SPL. We showed that by defining DSLs to capture high-level concepts we hide the complexity of transforming them into low-level concepts inside the DSL implementation. The DSL implementation becomes an asset shared across the SPL.

This LOP goal was achieved regardless of the choice of approach, internal DSLs over a declarative language or external DSLs over an imperative language. However, the cost of doing that differs significantly. In our case study, using internal DSLs proved to be nearly four times more cost-effective than using external DSLs. While the numbers may vary based on the nature of the SPL and the ratio between the size of the DSL implementations and the amount of DSL code, the advantage of using internal DSLs is evident.

From a reuse perspective, internal DSLs provide an additional advantage. Our ability to construct our DSL from two different DSLs (BNF and FBNF)

in the Cedalion implementation opens opportunities for reuse, since the BNF DSL can be used by itself, possibly for totally different kinds of products, and in conjunction with other DSLs. With MPS and external DSLs, combining DSLs is also possible, however, because of the code generation nature of the tool, we could not support such a separation in our case study. We actually started with a generic BNF DSL, but found it inapplicable for our needs, since it did not support variable bindings.

The case study in this paper provides the reader unfamiliar with LOP with a sense of how LOP can be leveraged for code reuse, and how language workbenches and LOP languages can help performing that task. Our case study shows an advantage for using declarative over the use of imperative programming as a base language. Surprisingly, despite this demonstrated (dis)advantage, the current state of the art is implementing LOP mainly using imperative languages (through language workbenches), instead of using declarative languages such as Cedalion.

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